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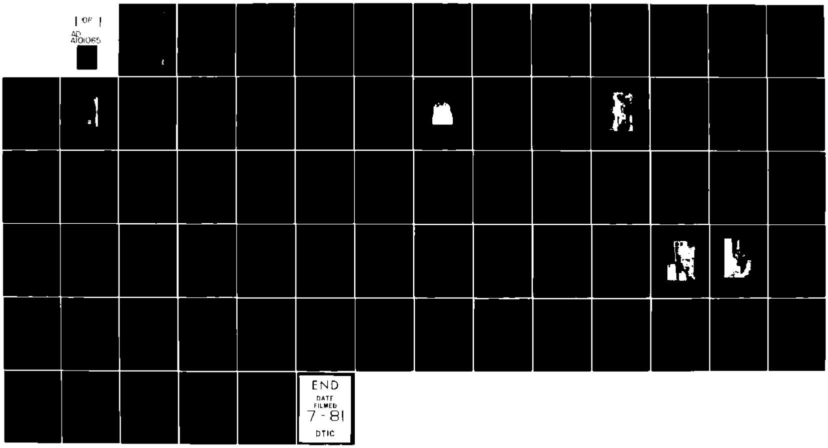

Manufacturing Methods and Technology Engineering for Batch Processing Neodymium Doped YAG Laser Rods

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November 1980

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The development of the fixturing and process for the batch fabrication of Nd:YAG laser rods is reported. The fixturing was designed to hold 16 (4.27 mm x 43 mm) laser rods during the grinding and polishing of both ends. The program goal of a fabrication rate of 12 rods per 8 man hours was achieved with the process developed.

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FOREWORD

This final technical report on the "Manufacturing Methods and Technology Engineering for Batch Processing Neodymium Doped YAG Laser Rods" was prepared by the Airtron Division of Litton Systems, Inc., Morris Plains, New Jersey under Contract No. DAAB07-77-C-0375 for the Solid State and Injection Laser Team of the U.S. Army Electronics Research and Development Command, Night Vision and Electro Optics Laboratory, Fort Belvoir, Virginia. Mr. W. Comeyne, team leader, was program monitor. The program was conducted to develop the mechanical and optical processes for multiple rod fabrication of neodymium doped YAG laser material over the period February 1977 through October 1979.

Section I

Summary

1.1 INTRODUCTION

The Nd:YAG solid state crystal laser is the most widely used and studied device for present and future military applications. Since its discovery in 1964[1], Nd:YAG has proved to be a nearly ideal laser material and increased rod requirements are a certainty for all service branches. Two persistent production problems have slowed the more extensive use of Nd:YAG in the form of low cost rods. The first of these was the availability of high purity and optically perfect rough boules capable of good yields. In 1970 the Army addressed itself to this area and a successful program was completed.[2] The second problem involves the fabrication of laser rods using techniques of batch processing in place of unit operations.

During the period 1970-1975, Nd:YAG laser devices experienced a period of advanced engineering development. At this stage the normal rod usage attained a maximum of 1-5 rods/month. Laboratory procedures for fabrication were developed and all operations were done by hand on each rod. At the present time the Army laser programs include items such as the AN-VVG-1 laser range finder, the GLLD locator designator, laser tank range finders, and the AN/GVS-5 hand held range finder. Similar programs and expanded plans are forecast for the Navy and Air Force. Thus the production

requirements of Nd:YAG are rapidly increasing and are already in excess of 500 rods per month. Thus it becomes imperative to develop procedures for laser rod fabrication which accomplish increased production yields per man hour. This program relied on the fact that high quality material is available. The preliminary machining operations necessary to produce rough rods of material are basically available as are the techniques required for the coating and testing of the finished rods. Therefore, this program was directed at developing techniques for the batch grinding and polishing of rough rods to produce finished laser rods.

Data available from prior attempts at batch fabrication of rods indicated what yields could be expected under laboratory conditions. Utilizing this information one phase of the program was directed at achieving the proper fixture design to achieve the required yields under production conditions. The development of the manufacturing process for grinding and polishing formed the other and longest phase. Included in the program was development or modification of any current test techniques or equipment.

1.2 LASER ROD SPECIFICATIONS

The laser rod configuration chosen for the development of batch grinding and polishing techniques is that of the component used in the AN/GVS-5 hand held laser range finder. This system represents the first system to go into volume

production and is thus appropriate to the development of manufacturing techniques. The rod itself is smaller in length and diameter than rods used in the majority of military systems. Other specifications, however, are typical.

The input material to the program is single crystal neodymium doped yttrium aluminum garnet (YAG). The dopant level is to be in the range of 1.0 to 1.3 atomic weight percent neodymium. From the single crystal boule, areas are selected which are of high optical quality. These areas are used to core drill rough rods which are subsequently centerless ground and sized in preparation for the final polishing operation.

The laser rod to be produced is a 4.27 millimeter diameter by 43 millimeter long rod. The outside diameter is to be of rough ground finish. Starting with rods of material having rough ground end faces, finished laser rods having a flatness within 0.2 wavelength of sodium light and a surface finish better than 20-5 per MIL-13830 are to be produced. The end faces are to be parallel to within 20 seconds arc and perpendicular to the rod axis within 5 minutes of arc. (See Table I for complete rod specifications)

1.3 FIXTURE DESIGN

At the start of this program the majority of the fixturing in application in laser rod fabrication was designed to hold a single rod during the grinding and polishing operations (Fig. 1). The laser rod to be polished is held at the center of the fixture surrounded by polishing feet. When one end of the rod is polished

Table I

Laser Rod Specifications

Characteristic	Specification	Test Method
Nd Dopant	1.0 - 1.3 atomic %	Fluorescent Lifetime
Dimension	Length 43.0 mm $^{+2}_{-0}$ mm	Calipers
	Dia. 4.27 $\pm$ 0.02 mm	Micrometer
Surface Quality	20 - 5	Comparison Standards
Surface Flatness	$\lambda/5$	Optical Flat
Parallelism	20 sec	Fizeau Interferometer
Perpendicularity	5 min	Autocollimator
Strain	<1/2 Fringe/25.4 mm	Twyman Green

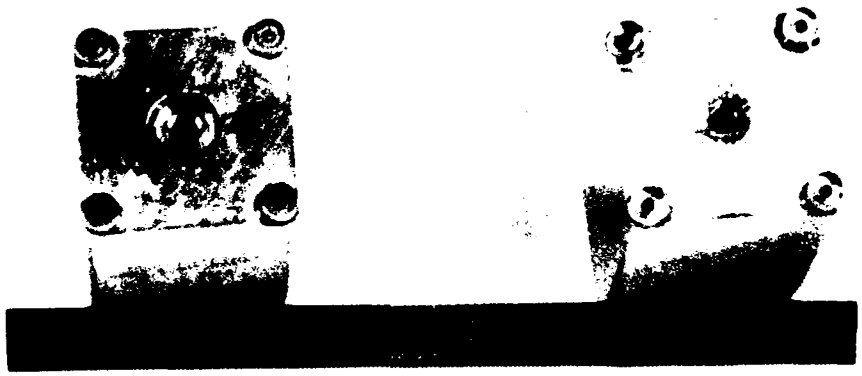

Figure 1   Single Rod Polishing Blocks

the rod is dismounted, turned and remounted. The second end is then ground and polished. This process yielded one rod per 5 man hours.

The experiments previously performed on batch fabrication indicated the yields that could be expected from a fixture designed to hold 12 rods (Table II). This data showed that under laboratory conditions and for the rod sizes attempted yields of 65-85% could be achieved when the critical parameters were considered. This information in addition to rod specifications formed the basis of the fixture design.

1.3.1 DESIGN REQUIREMENTS

Three basic requirements existed for the design of an appropriate fixture for batch grinding and polishing.

1) The fixture must hold a sufficient number of rods such that when yield characteristics are considered the design goal of the program will be achieved.

2) The design must be such that rod specifications are met with a reasonable yield.

3) The size and design of the fixture must provide for the fact that the grinding and polishing would be performed by hand. In order for the fixture to perform well in a manufacturing process all of the above criteria would have to be met.

The number of rods held by the fixture is derived from the yield data generated in earlier experiments. The design goal of the program was to achieve a rate of 12 fabricated rods per 8 man hours. Assuming that a batch of

Table II

Results of Multiple Rod Fabrication Experiments (Laboratory Conditions)

Number of Rod Which Meet Specification Below

.250" x 2.6" Rods	$\lambda/5$ Flat	20 sec. Parallel	5 min. Perpendicular	20-5 Surface Finish
Block No. 1	12	11	12	7
Block No. 2	12	12	12	10
Total	24	23	24	17
3mm x 50mm Rods				
Block No. 1	12	12	12	12
Block No. 2	12	10	11	12
Total	24	22	23	24

Notes: 1) Each block holds 12 rods.

rods could be completed within the stated time, then yield of rods meeting specifications would determine the process rate. Assuming a yield of approximately 75% the fixture should then hold 16 laser rods.

The most critical rod specification in terms of the actual grinding and polishing operations are parallelism, perpendicularity, surface flatness and surface finish. To meet these criteria the fixture must be designed so that

1) the rod is unstressed when mounted

2) rods must be held such that the face polished is perpendicular to the rod barrel within 5 minutes.

3) the mounting pattern must be symmetric so that faces work evenly and proper flatness is obtained.

4) polished faces must be protected from contamination and potential damage.

1.3.2 FINAL DESIGN

The final design adopted for the fixture is shown in Figure 2. The block is 3 inches in diameter and 1 9/16 inches thick. The block has flats ground on the sides to provide a convenient method of resting the block. It is made of a quality tool steel. The thickness was chosen to accomodate the 44mm length rods leaving both ends exposed.

To provide mounting for the laser rods, holes are bored through the block. There are 8 holes located on each of two bolt circles - one 1.562 inch in diameter and the other 1.062 inch diameter. The hole is 5/16 inch diameter

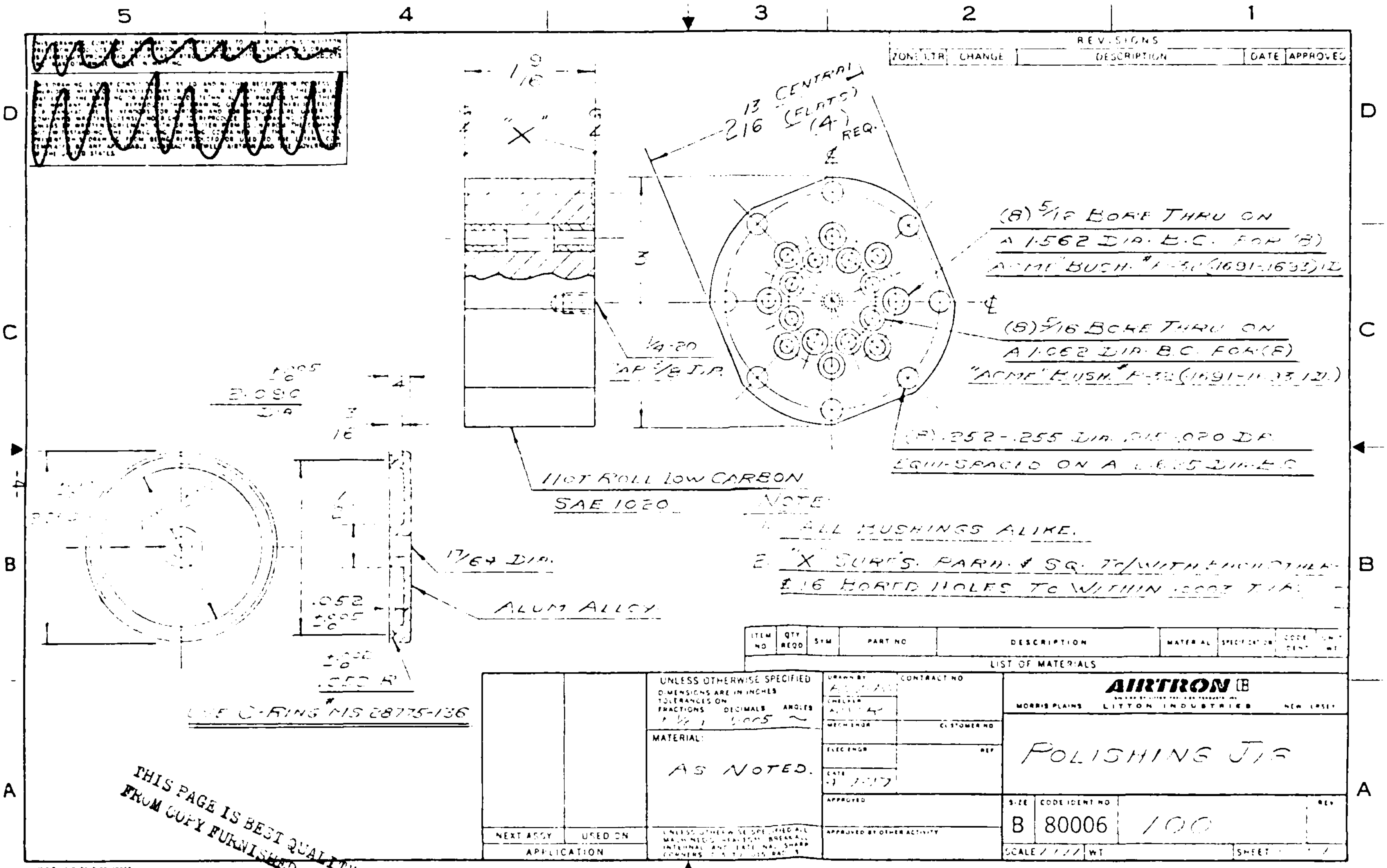

Figure 2 Polishing Jig

to accept a standard size bushing. The bushings are pressed into the block at each end. The bushings hold the rod at each end without constraining the center. This technique eliminates the stressing of the rod in the fixture.

1.3.3 PROTECTIVE CAP

During the finishing of the laser rod second ends, it is possible for the first ends to become contaminated with the polishing grit and subsequently damaged. To prevent this, the finished ends are covered with an aluminum protective cap. This cap is 2.25 inches in diameter. It is held in place using a 1/2-20 bolt and uses an "O" ring seal.

The holes in the block are perpendicular to the face within 0.0003" TIR or to less than 1 minute. Assuming the smallest rod diameter and the largest bushing inside diameter allowed, the rod and bushing perpendicularity is within 2.5 minutes. Thus a perpendicularity of less than 3.5 minutes should be maintained for all rods.

Polishing feet or dummies are located on each end of the block on a 2.625 inch diameter bolt circle. Each rod is thus symmetrically surrounded and the surface will work evenly. In addition, the block will be stable. The spacing of the bolt circles allows sufficient spacing to install a cover over finished ends of the rods to protect them from contamination, while leaving the dummies exposed such that parallelism can be monitored. A photograph of the polishing fixture is shown in Figure 3 and a comparison to a single rod fixture in Figure 4.

Figure 3 Polishing Fixture

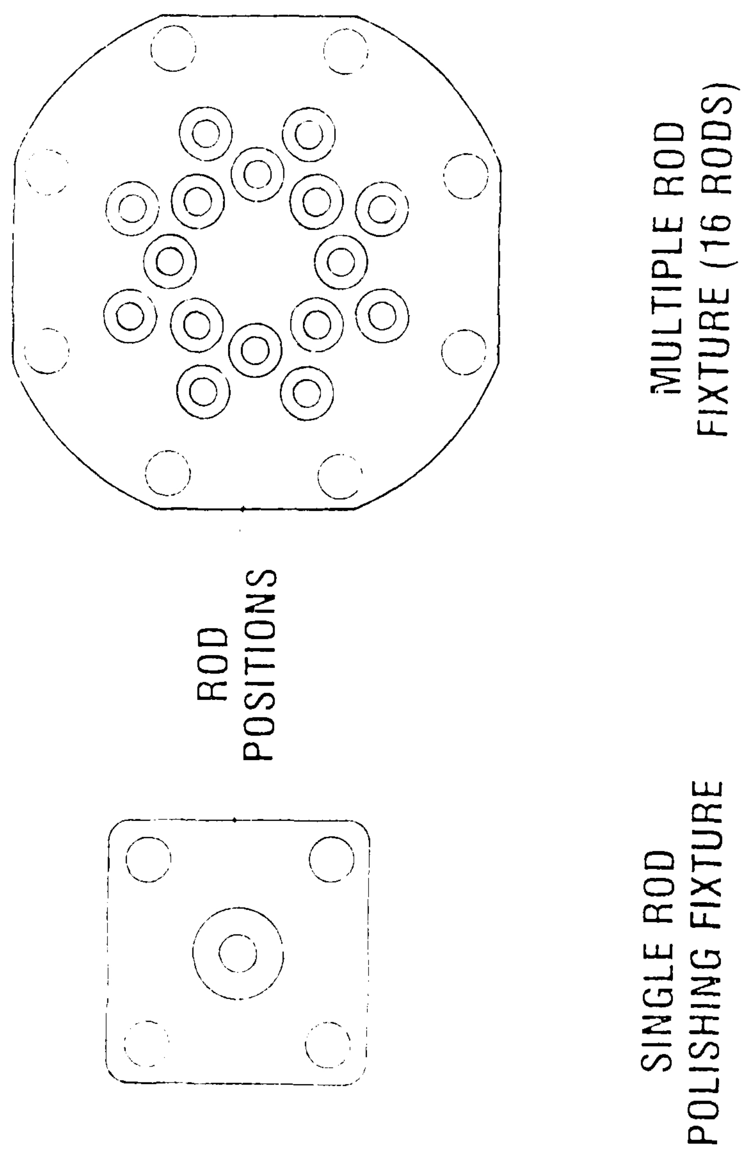

Figure 4 Jig Comparison

1.3.4 WORK STATION

The work table in Figure 5 is of a very basic design and has been used extensively for single rod fabrication. It consists of a vertical mounted shaft, tapered at the top end to accept the different types of polishing and grinding tools. A pulley is attached at the bottom end, which is connected to a variable-drive motor by a belt. The use of a variable-drive motor allows the operator to select the proper rotation rate for the particular lap and grit being used and thus maintain the flatness of the lap. The table top dimensions are two feet deep by three feet wide. This size table permits the operator some working counter space for the polishing or grinding powders when the eight inch tool is mounted on the spindle.

A clear plastic shield two feet high covers three sides of the table. This helps to eliminate cross contamination from other tables and lets the front open for access to the spindle. A clear top is also used to help stop airborne debris from falling directly onto the tool.

1.4.0 MANUFACTURING PROCESS

The manufacturing process for a Nd:YAG laser rod starts with a boule grown by the Czochralski method. The as grown boule is examined for areas free of gross strains and scatter. These areas are cut from the boule, rough polished and reexamined. Those areas free of strain and scatter are indicated for laser rods. Rough rods of

Figure 5   Laser Rod Polishing

material are then core drilled from the boule using diamond-tipped tools. The rods are centerless ground to the proper diameter and ground to length.

The rods are wax mounted in the polishing fixture by heating the block with the rods in place and then applying wax to the rod barrels. The final grinding and polishing operations are accomplished by mixing the proper slurry on a lap and using the work station previously described. The grit size of the slurry is successively reduced to attain the surface finish required. The grinding and polishing operations are performed in the same method for both end faces of the rods and are performed by hand.

During the processing of the first ends, the block is monitored dimensionally and by examining the uniformity of the surface finish to assure that the entire surface is being worked evenly. Dimensions are controlled to within 0.0002 inches. In processing second surfaces, the parallelism of the surfaces is monitored, first dimensionally, then by autocollimator, and finally using a Fizeau interferometer. Throughout these operations surface finish is frequently examined to assure that the proper finish is obtained.

Following completion of the process, rods are dismounted and inspected. The completed rods are then coated and prepared for shipment. The two critical operations for this process are the mounting and grinding and polishing

operations. These are discussed in the following sections.

1.4.1 MOUNTING

The first part of the work carried out under this contract was directed toward the design and evaluation of the polishing block. The first several runs carried out followed the process described for the first ends of the rods. This was to assure that the fixture was properly toleranced and that the required perpendicularity could be achieved. The results of the these runs are shown on Table III. It can be seen that results for all rods fell well within the required specifications. These results were repeated in all subsequent runs.

The other area of concern in terms of the fixture and mounting technique was the ability to attain an unstressed condition. The polishing fixture was designed such that a relieved area existed at the rod center to reduce the possibility of a stressed condition existing. Initial results, however, showed that a considerable change in parallelism was occurring when rods were dismounted (Table IV). The mounting and dismounting technique used was to simply heat the block with the rods in place on a hot plate and apply an appropriate wax.

To reduce the changes being observed several different waxes were tried. More uniform heating was also attempted through the use of an oven. These produced varying degrees of success (Table V). It was found that changes could not be

Table III

Perpendicularity

Position	Perpendicularity (min.)		
	Run I	Run II	Run III
1	3.0	3.5	-
2	2.0	2.0	3.0
3	1.0	1.5	0.75
4	2.5	1.5	1.5
5	1.0	1.5	2.0
6	1.0	0.5	0.5
7	0.5	1.5	1.25
8	1.5	3.5	3.0
9	0.75	2.0	1.5
10	0.75	0.5	1.0
11	1.0	0.7	3.0
12	0.5	1.5	2.0
13	2.0	1.5	3.0
14	2.0	0.5	1.0
15	1.5	1.5	3.0
16	0.5	0.5	1.0

Table IV

Specification Achieved - Double End Polishing

Position	Perpendicularity (min.)	Flatness (λ)	Surface Finish (Better than 20-5)	Parallelism (sec.) Before	After	Change
1	2.5	.1	yes	<10	17	7
2	3.0	.1	yes	<10	17	7
3	2.0	.1	yes	<10	<10	-
4	1.0	.1	yes	<10	26	16
5	3.0	.1	yes	<10	<10	-
6	2.0	.1	yes	<10	<17	7
7	1.0	.1	yes	<10	10	-
8	1.0	.1	yes	<10	<10	-
9	1.0	.1	yes	13	17	4
10	2.5	.1	yes	<10	<10	-
11	2.5	.1	yes	<10	13	3
12	1.5	.1	yes	<10	22	12
13	3.0	.1	yes	13	17	4
14	1.5	.1	yes	<10	13	3
15	3.0	.1	yes	<10	26	16
16	1.5	.1	yes	13	17	4

Table V

Parallelism - Oven Mounting

Position No.	Parallelism Before (sec.)	Parallelism After Mounting (sec.)	Change (sec.)
1	12	30	18
2	10	15	5
3	20	35	15
4	20	16	4
5	12	18	6
6	11	13	2
7	11	11	-
8	10	10	-
9	15	30	15
10	15	21	6
11	26	40	14
12	10	30	20
13	9	15	6
14	13	16	3
15	9	31	22

eliminated but they could be minimized by careful application of the mounting wax. It was most critical that a uniform coating of wax be applied to the rod barrel where it would contact the bushing. This is achieved by heating the block with the rods in place. The rods are withdrawn from the block and the wax applied. The rods are slid back into the block and rotated about their axes to assure an even coating of wax.

1.4.2 GRINDING AND POLISHING

The largest portion of the work performed under this contract was on the grinding and polishing operations. A process had to be established and verified that would reproducibly manufacture laser rods to the required specifications with good yield and within a reasonable time.

The initial experiments performed in this phase of the program were to determine the time involved in the various steps of the process. The time for each step was measured including both actual process time and the total time involved including tool preparation and measurement time. The result of these measurements are shown on Tables VI and VII. The average total time is well below the eight hours required under this program. However, it can also be seen that to achieve further reductions, one should seek to reduce the measurement time and other process times peripheral to the actual grinding and polishing. In future work-station design it would be advantageous to have the necessary

Table VI

Grinding and Polishing Time

No Inspection

Operation	Time (min.)
Grind - 1st end	10
Polish - 1st end	25
Grind - 2nd end	12
Polish - 2nd end	30
Total	77

Table VII

Process Time

Operation	Average Time (Hours)
1st end grind	1
1st end polish	1.2
2nd end grind	2.1
2nd end polish	2.7
Total	7.0

measurements capability as close to the operator as possible.

The majority of the operators in an optical polishing facility mix their grinding and polishing slurry by "feel". For this work it was decided to measure the starting composition used by several operators. The result of these measurements are shown in Table VIII. These compositions were used successfully in several polishing runs. Most operators, however, still prefer to use feel to determine the best composition. This approach is not only acceptable but necessary when one considers that as grinding and polishing proceeds the slurry changes composition as water evaporates or slurry is removed from the lap. Frequently water must be added during the course of the operation to prevent the lap from drying out.

Table VIII also shows the results of measurements made on material removal. These values were consistent from run to run. The largest variation reported occurred during the polishing of second ends when parallelism is the principle parameter controlled. The amount of material removed at this step is directly dependent on the correction necessary to achieve proper parallelism. This table also gives the lap rotation rate values found to be an acceptable starting point.

During this phase of the program the number of strokes of the block across the lap in each direction was also

Table VIII

Manufacturing Process

Step	Slurry Grit (grams)	Slurry Water (ml)	Lap Rotation Rate (rpm)	Approximate Material removal (in.)
Grind 20μ Al_2O_3	50	50	8	0.002
Grind 12μ Al_2O_3	40	40	8	0.0005
Grind 5μ Al_2O_3	25	40	8	0.0003
Polish 1μ Al_2O_3	10	50	8	0.0004
Polish 0.3μ Al_2O_3	1	50	8	-

documented. The result of all of the above work formed the basis for the process specification of Section 2.

1.5 DATA AND RESULTS

During this program 15 blocks of rods were processed on which a complete record of fabrication data and processing times were recorded. In addition to these, the process was applied to the fabrication of rods for use in the manufacture of the AN/GVS-5. This latter case represented a rate of 5 to 6 blocks of rods per month during the later stages of the contract. In all cases the fixturing and process developed during this program were used.

The data presented in this section is a compilation of the data on the 15 runs. Rods were tested in accordance with the test plan described in Section 3. The results achieved in applying this process are summarized in Table IX. The complete data on the 142 rods delivered are found in Appendices 1 - 3.

Table IX is divided into the three parts of the program and the number of rods required for delivery is indicated along with the approximate number of polishing runs made. The table shows that certain of the parameters present nc problem in multiple rod fabrication. Fluorescent Lifetime is a material specification and control is achieved by proper selection of material from the boule.

Rod diameter is established during the preliminary machining operation of centerless grinding. Rod length is

Table IX

Results of Multiple Rod Manufacturing Process

			Percent Yield								
Program phase	Number of rods req'd	Number of polishing runs	Fluorescent lifetime	Length	Diam	Surface Quality	Flatness	Parallelism	Perpend.	Strain fringe	Yield (1)
Engineering (2)	12	3	100	100	100	90	100	98	100	100	90%
Confirmatory (3)	3[illegible]	3	100	100	100	94	100	81	100	100	80%
Pilot Production	100	9	100	100	100	98	100	98	100	100	96%

Notes:

(1) Percent yield may be higher than product of individual yield since rods may be rejected for more than one reason.

(2),(3),(4) For data on delivered rods see Appendix 2,3,4 respectively

controlled by measuring length during processing. Since 16 rods are worked simultaneously, if one rod in the block is out of tolerance all would be. Yields of 100% are also achieved for surface flatness. This reflects the fact that with a multiple rod block the flatness of a large surface (6.5cm) is being controlled while final measurement is on a 4.27 mm diameter rod.

As described in the section on fixture design a total perpendicularity error of less than 3.5 minutes is expected if all machining tolerances are adhered to. The results indicate that the 5 minute specification is easily achieved and verifies the tolerancing of the fixture. The fact that all rods met the 0.50 fringe per 25.4 mm of length requirement on strain refers to the material selection process rather than the polishing process.

The two parameters most difficult to control during processing were parallelism and surface finish. In neither case were yields of 100% achieved. This is due to the difficulty of obtaining the proper surface finish and parallelism on all parts at the same time. In correcting one of the rods for a surface finish or parallelism problem, there is a high probability of developing a surface defect or driving another rod out of parallelism. For this reason processing is normally stopped prior to achieving 100% yield with respect to these two parameters. However, average yields for these

two parameters are still in excess of 90% as is the overall yield.

The average time required to grind and polish a block of rods is approximately 7 hours. The time for each of the 15 blocks processed is shown on Table X. This shows that an overall rate in excess of 14 rods per 8 man hours is achieved. For the processing of single rods a rate of 1 rod per 5 man hours is estimated. This means that through the implementation of this program an eightfold increase of rods processed per day is achieved.

1.6 CONCLUSIONS

The design goal of this program was to achieve a laser rod manufacturing rate of 12 rods per 8 man hours. During the engineering phase of the program the necessary tooling and process were developed to fabricate blocks of 16 laser rods of the AN/GVS-5 configuration. The results of the program indicate that a rate in excess of 14 rods per 8 man hours was achieved, thus exceeding the rate required by the program.

No major difficulties were encountered in achieving the desired rate at the rod specification required. A minor difficulting was originally encountered in controlling changes in parallelism between mounted and dismounted rods. This was overcome by exercising more care in mounting.

Rate variations between blocks were significant. These

Table X

Process Time Per Block

Run	Process time (hours)
1	8.0
2	6.5
3	12.0
4	8.0
5	3.0
6	13.0
7	10.0
8	8.0
9	8.C
10	6.0
11	3.75
12	4.25
13	4.0
14	4.5
15	5.5
Average	7.0

variations were found to be independent of the operator and were minimized during the later stages of the program when more experience with the process was gained.

The program was successful in achieving a dramatic reduction in the number of man hours required to fabricate a finished laser rod. The process has been applied to the fabrication of in excess of 1500 laser rods for use in the AN/GVS-5 handheld laser rangefinder. As part of this program a process demonstration was held. The list of attendees is found in Appendix 5.

1.7 RECOMMENDATIONS

The process developed was successful for 4.27mm by 43mm laser rods. In future work the results of this work should be extended to other sized laser rods. In addition this work was directed at a parallelism tolerance of 20 sec. of arc. For many applications a tolerance of 10 seconds is required. In this work a significantly reduced yield is obtained at this level. Efforts at improving the yield at this specification should be made.

This process relies heavily on the operator to control parameters. If even higher process rates are required, it will be necessary to develop processes where this reliance on the operator is reduced.

Section II

MANUFACTURING PROCESS

2.1 INPUT MATERIAL

The input material to the final grinding and polishing operations are rods of neodymium doped yttrium aluminum garnet (YAG). The dopant level is 1.0-1.3 atomic percent neodymium. The rough rods of material are 4.27 mm in diameter and 43.25 to 45 mm in length. The diameter is that required for the finished rod and the range of lengths provides sufficient material to be removed during the grinding and polishing operations. Leaving too much material on the rough rods is to be avoided as prolonged grinding times would result. A flow chart of the manufacturing process is shown in Figure 6.

2.2 MOUNTING

In preparation for the grinding and polishing operations 16 rods are placed in the block in a horizontal position. This assembly is heated on a hot plate until the wax flows freely when placed on the rods. One end of the rods and then the other is removed from the block and coated with wax. The rods are rotated while being replaced in the block to spread the wax evenly. The block is placed on a flat glass with the rods in a vertical position and allowed to cool. The rods and feet are then lightly ground using a surface grinder such that they will present a uniform surface during the final finishing operations and limit the amount of grinding required in subsequent steps.

Flow Chart of the Manufacturing Process

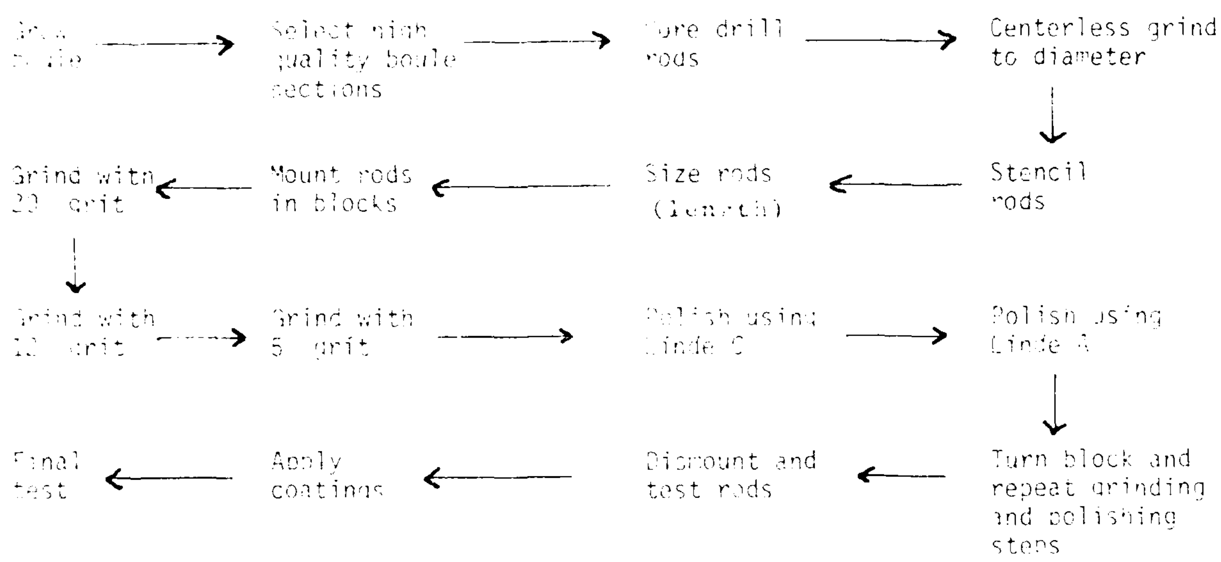

Figure 6 Flow Chart of Manufacturing Process

2.3 TWENTY MICRON GRINDING

2.3.1 Select proper lap, mark grinding, and clean thoroughly using a mild detergent and water.

2.3.2 Clean polishing machine to make sure all residual polishing compounds from previous operations are removed.

2.3.3 Using spherometer measure lap- if not flat grind lap using 20μ Al_2O_3 until flat. Install lap on polishing machine along with protective plastic ring.

2.3.4 Using a comparator measure length of rods in block at several positions.

2.3.5 Apply 50 grams of 20μ Al_2O_3 to lap and add 50 ml of water. Mix until slurry is formed and distribute over lap.

2.3.6 Using timer set proper lap rotation rate- 8 rpm.

2.3.7 Place block of rods on lap and apply 80 strokes rotating block by 90° after each 20 strokes. (The term strokes applies to the operator moving the block across the lap and back. This is done in an approximate figure eight configuration.)

2.3.8 Remove block from lap and measure length and check surface finish. If grinding marks remain or rods not working evenly replace block on lap.

2.3.9 Continue grinding until a 20μ surface finish is obtained and rods are being evenly worked (no point to point variation in rod length). Additional water can be added to the slurry to maintain the proper consistency.

Approximately 0.002 inches is removed during this process.

2.3.10 After completing run, clean block and lap thoroughly using a mild detergent and water.

2.4 TWELVE MICRON GRINDING

2.4.1 Repeat steps 2.3.1 through 2.3.4 as required.

2.4.2 Apply 40 grams of 12μ Al_2O_3 to lap and add 40 ml of water. Mix until slurry is formed and distribute over lap.

2.4.3 Using timer set lap rotation rate of 8 rpm.

2.4.4 Place block on lap and apply approximately 80 strokes rotating block by 90° after each 20 strokes.

2.4.5 Remove block from lap, clean, measure lengths and check surface finishes. If proper surface finish has not been obtained or all block positions are not of equal lengths return block to lap and continue grinding.

2.4.6 During grinding it may be necessary to apply more pressure to one side of the block than the other to get all rods of equal length. This can be accomplished by holding the block in place off center on the lap with the block side requiring additional material removal furthest from the center. Lap rotation rate may be increased to accelerate the process.

2.4.7 When 12 micron finish is obtained and all rods are working evenly remove block and proceed to next step.

2.5 FIVE MICRON GRINDING

2.5.1 Repeat steps 2.3.1 through 2.3.4 to assure that lap and block are properly cleaned.

2.5.2 Apply 25 grams of 5μ Al_2O_3 to lap and add 40 ml of water. Mix to form slurry and distribute evenly over surface of lap.

2.5.3 Using timer set lap rotation rate to 8 rpm.

2.5.4 Place block on lap and grind for approximately 400 strokes. This should take about 5 minutes. Again an equal amount of time should be spent in grinding in each of four positions 90° apart. The rod end faces are checked to make sure a 5μ finish is obtained. The processing time is nominal since surface finish determines when process is complete.

2.5.5 When proper surface finish is obtained clean block and tools using detergent and water and proceed to the polishing process.

2.6 ONE MICRON POLISHING

2.6.1 Select proper lap, marked polishing, and clean thoroughly using detergent and water.

2.6.2 Clean work station to remove any residual polishing compounds from previous polishing steps.

2.6.3 Measure rod lengths using comparator. From this point on the polishing feet should be used for measurement to avoid any damage to rod end faces.

2.6.4 Prepare slurry on lap mixing 10 grams of 1 micron Al_2O_3 to 50 ml of water. Approximately 5 ml of a suspension agent are added to reduce aglomerates. The slurry is mixed and spread evenly over the lap.

2.6.5 Using timer set lap rotation rate of 8 rpm.

2.6.6 Place block on lap and polish for 400 strokes rotating block by 90° after each 100 strokes.

2.6.7 Remove block from lap, clean and inspect surface finish. If pits and scratches remain return to lap and repeat step 2.6.6 adding additional water to slurry as required.

2.6.8 Continue polishing and inspecting until a surface finish free of pits is obtained and desired flatness achieved. Some scratches will remain at this point. The parts are now ready for the next step.

2.7 0.3 MICRON POLISHING

2.7.1 Repeat steps 2.6.1 through 2.6.3.

2.7.2 Prepare slurry by mixing one gram of 0.3 Al_2O_3 and 50 ml of water. Mix slurry and distribute evenly over lap.

2.7.3 Using timer set lap rotation rate at 8 rpm. rotating block by 90° after each 100 strokes.

2.7.4 Place block on lap and polish for 400 strokes rotating block by 90° after each 100 strokes.

2.7.5 Remove block from lap, clean and inspect surface finish. If scratching remains in excess of specification return to lap and continue polishing. Additional water can be added to the slurry as required to maintain proper consistency.

2.7.6 Do not contact rod end faces during inspection as scratching may result.

2.7.7 Continue polishing and inspecting until specified surface finish is obtained. Rods are then cleaned and readied for second end grinding and polishing.

2.8 SECOND END PROCESSING

2.8.1 Install cover on block to prevent any damage to rod end faces already polished.

2.8.2 Repeat grinding and polishing operations as outlined in paragraphs 2.3 through 2.7.

2.8.3 In step 2.6.7 check rod end face parallelism using Fizeau interferometer.

2.8.4 When second ends are finished the block is thoroughly cleaned and rods are dismounted by heating the block on a hot plate until the wax softens and rods are easily slipped out.

2.8.5 Rods are cleaned of residual wax, packaged and submitted for further testing.

Section III

QUALITY CONTROL TESTS

3.1 NEODYMIUM DOPING LEVEL - The laser rod material shall consist of single crystal, neodymium doped yttrium aluminum garnet. Doping of the neodymium shall be 1.0 to 1.3 atomic percent substituted for yttria in the crystal. (Dopant density range: 1.38×10^{20} to 1.8×10^{20} ions per cm^3).

3.1.1 REQUIREMENT

Fluorescent lifetime to be between 206 and 235μ sec.

3.1.2 PROCEDURE

3.1.2.1 Set up apparatus as in Figure 7.

3.1.2.2 Insert the test specimen in the apparatus, adjust oscilloscope vertical sensitivity such that peak of the fluorescent intensity represents a full scale deflection.

3.1.2.3 Adjust horizontal scale to 100μ sec per division.

3.1.2.4 With these conditions make an exposure of the resulting fluorescent intensity trace.

3.1.2.5 Keeping all settings the same, replace the sample with a piece of clear YAG and make a second exposure on the same photograph, to extablish a baseline.

3.1.2.6 Process the photographic record.

3.1.2.7 From the photograph measure fluorescent intensity as a function of time.

3.1.2.8 Calculate fluorescent lifetime from $t = (t_2 - t_1) \ln (I_1/I_2)$ where: t = Effective fluorescent lifetime of the sample; t_1, I_1 are the time and intensity respectively approximately 100 seconds after the onset of the pulse;

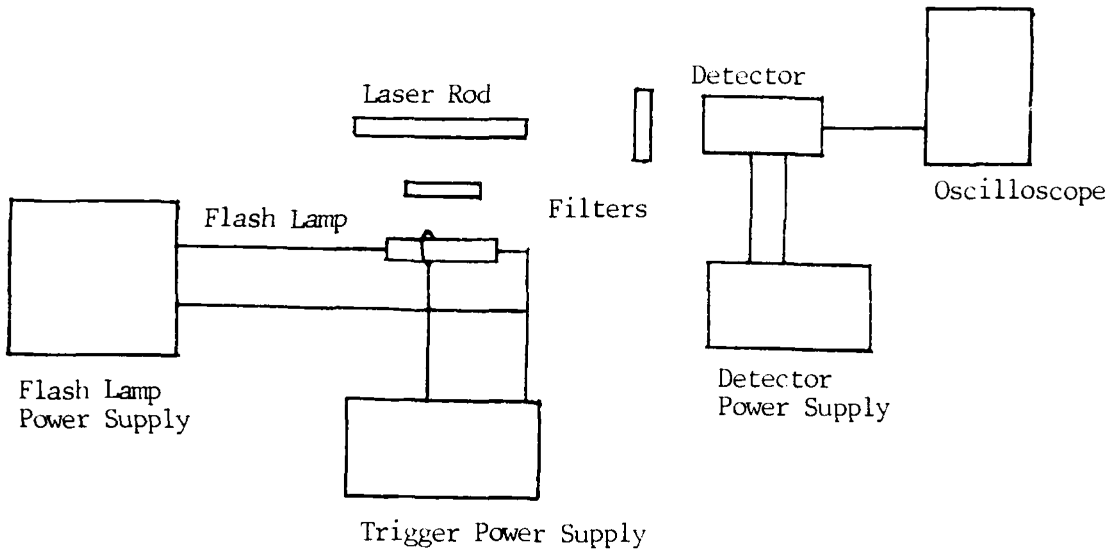

Figure 7 Fluorescent Lifetime Schematic

t_2, I_2 are the time and intensity respectively at $t_2 = t_1 + 100\mu$ sec.

3.1.2.9 Repeat the calculation of 3.1.2.8 for several time intervals.

3.1.3 ACCEPTANCE

Acceptable parts will have fluorescent lifetimes that fall in the range of 206μ sec to 235μ sec.

3.2 DIMENSIONS

3.2.1 REQUIREMENTS

3.2.1.1 Diameter - 4.27 ± 0.02 mm

3.2.1.2 Length - $43.0 \begin{smallmatrix} +2.0 \\ -0.0 \end{smallmatrix}$ mm

3.2.1.3 Clear Aperture - 4.00 ± 0.02 mm

3.2.2 PROCEDURE

3.2.2.1 Using a calibrated micrometer with a least count of 0.01 mm or less, measure the part diameter.

3.2.2.2 Using a calibrated vernier caliper having a least count of 0.1 mm or less, measure the part length.

3.2.2.3 Using the Nikon shadowgraph, measure the clear aperture of the part.

3.2.3 ACCEPTANCE

Acceptable parts will be within the required tolerances on all dimensions measured.

3.3 SURFACE QUALITY

3.3.1 REQUIREMENT - End surfaces shall be polished to a surface quality of 20-5.

3.3.2 PROCEDURE

3.3.2.1 Using a binocular microscope and microscope illuminator, examine the surface under test for the presence of any scratches or digs.

3.3.2.2 Where defects do exist, compare to scratch and dig standards for determination of size.

3.3.2.3 Record number and sizes of defects observed.

3.3.3 ACCEPTANCE

Acceptable parts will not exceed the number and sizes of defects allowed per MIL-O-13830.

3.4 SURFACE FLATNESS

3.4.1 REQUIREMENT

The ends shall be flat to within 0.2 wavelength of sodium light (5898A).

3.4.2 PROCEDURE

3.4.2.1 While rods are still in polishing block place the optical flat over the surfaces and observe the resulting fringe pattern.

3.4.2.2 Perform under illumination at 5898A.

3.4.3 ACCEPTANCE

Acceptable parts will show fringe curvatures that are less than 0.4 fringes (0.2 waves).

3.5 PARALLELISM

3.5.1 REQUIREMENT

The ends shall be optically parallel to within 20 arc seconds.

3.5.2 PROCEDURE

3.5.2.2 Place rod under test in beam as shown in Figure 8. This can be done either while rods are still mounted in fixture or after dismounting. Final measurement

is done on unmounted rods.

3.5.2.3 Adjust the sample holder to produce the pattern with the minimum number of fringes.

3.5.3 ACCEPTANCE

Acceptable parts will have less than 2.25 fringes across the clear aperture.

3.6 PERPENDICULARITY

3.6.1 REQUIREMENT

The ends shall be perpendicular to the rod axis within 5 minutes of arc.

3.6.2 PROCEDURE

3.6.2.1 Place the rod under test in a vee block in the field of view of the autocollimator. (Figure 9)

3.6.2.2 Align the rod end surface with the autocollimator such that the reflection from the rod end face is seen in the autocollimator.

3.6.2.3 Rotate the rod about its longitudinal axis and measure the total runout.

3.6.3 ACCEPTANCE

Acceptable parts will have total runouts of less than 10 minutes of arc.

3.7 STRAIN

3.7.1 REQUIREMENT

No more than one half (1/2) strain free fringes per 25.4 mm of rod length are allowable when analyzed by double-pass Twyman Green interferometry.

3.7.2 PROCEDURE

3.7.2.1 The rod under test is placed in the

Figure 8   Fizeau Interferometer

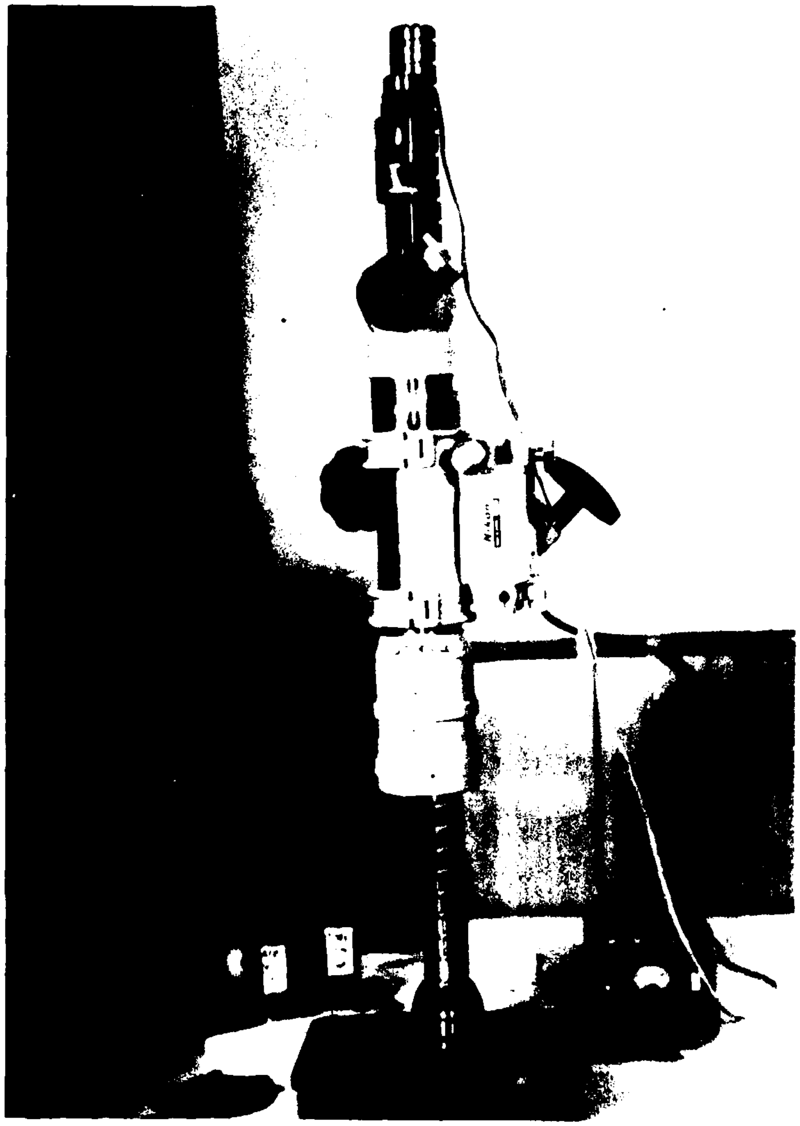

Figure 9 Autocollimator

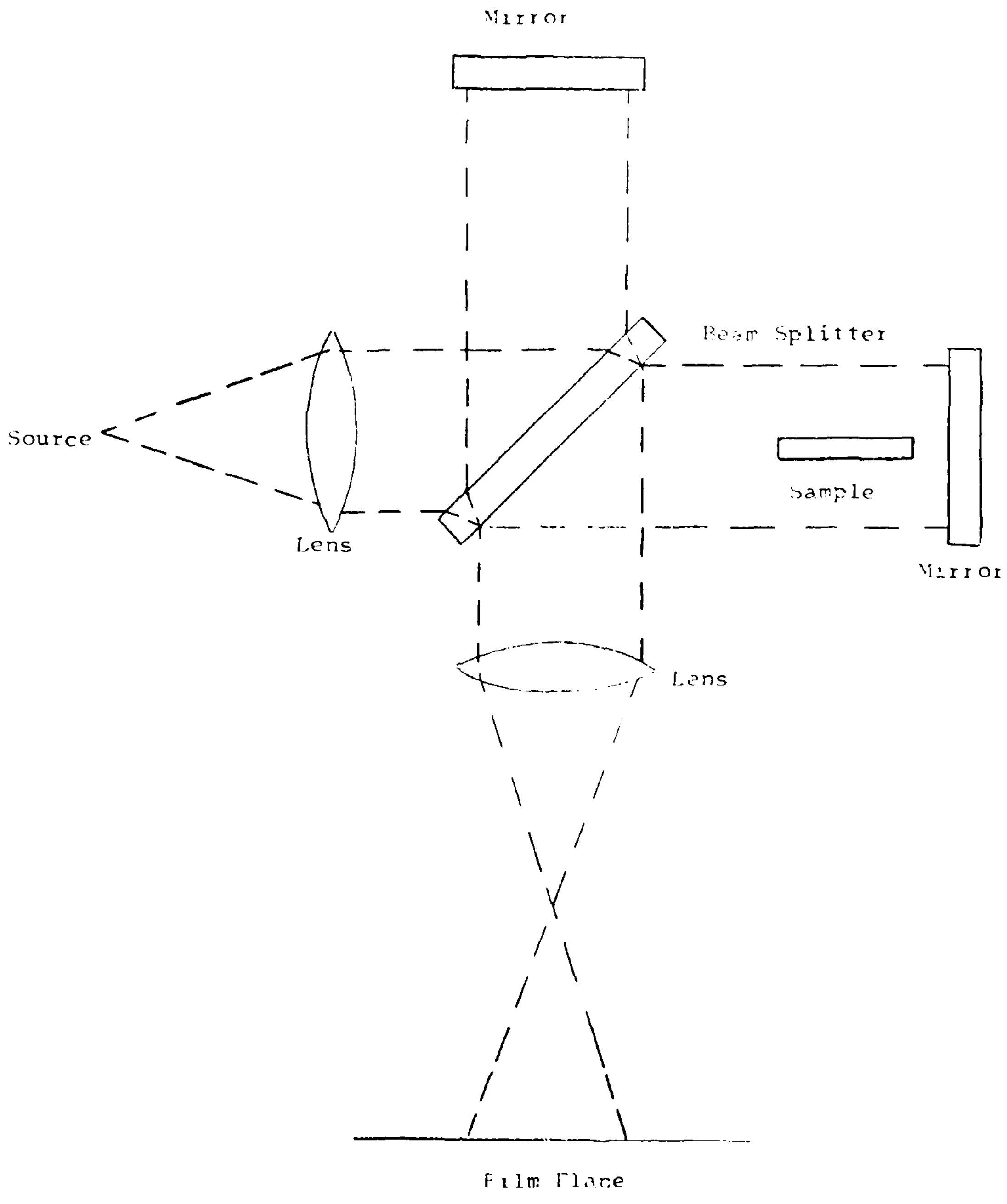

Figure 10 Twyman Green Interferometer Schematic

working arm of a Twyman Green interferometer (see Figure 10).

3.7.2.2 The working mirror is adjusted such that approximately three fringes are across the rod aperture.

3.7.2.3 A photograph of the resulting fringe pattern is then taken.

3.7.2.4 From this pattern the maximum curvature of the fringes is determined by measuring the average fringe spacing and the maximum deviation of the fringes from a straight line.

3.7.2.5 The ratio of the deviation to the average spacing is calculated and expressed in units of fringes.

3.7.3 ACCEPTANCE

Acceptable rods will have total distortions of less than 0.85 fringes.

3.8 MARKING

3.8.1 REQUIREMENT

Each rod shall have a serial number such that individual rods can be identified. The AR coated end of each rod shall also be identified with a dot or similar mark.

3.8.2 PROCEDURE

3.8.2.1 Hold rod up to light and look through rod or examine diameter of rod under microscope illuminator.

3.8.2.2 Look for serial number and dot under above conditions.

3.8.2.3 Verify that dot is on antireflection coated end of rod.

3.8.3 ACCEPTANCE

Acceptable rods will have a visible serial number and a dot at the AR end.

3.9 END COATING REFLECTIVITY

3.9.1 REQUIREMENT

One end surface shall be dielectric coated to have 60% $\pm$ 3% reflectivity for 1.0644 micron radiation. The opposite end shall be antireflection coated with a low loss hard coating in accordance with MIL-C-675. This coating shall have a reflection loss no greater than 0.25% for 1.0644 micron radiation when in a medium with a refractive index of 1.0.

3.9.2 PROCEDURE

Wafer samples are coated with the lot of rods being processed. One sample is coated with the reflective coating lot and one with the antireflection coating lot. Using the Cary 14 Spectrophotometer with a reflectivity measuring attachment, a trace of the reflectivities of each of the samples is obtained. From these traces the reflectivity at 1.064μ is measured.

3.9.3 ACCEPTANCE

Acceptable rods will be from reflective and antireflective coating lots that have measured reflectivities of 60% $\pm$ 3% and less than 0.25% respectively.

3.10 END COATING CLEANING

3.10.1 REQUIREMENT

The coatings shall be capable of withstanding repeated cleaning and immersion in polar organic solvents

without peeling, separating or changing in optical properties.

3.10.2 PROCEDURE

Immerse coating witness sample in alcohol, remove and allow to dry. Repeat a minimum of six times. Then repeat and using methyl alcohol and then acetone. These immersions are to be performed for both reflective and anti-reflective coating samples.

3.10.3 ACCEPTANCE

Acceptable coating lots will reveal no degradation in either visual appearance or optical characteristics.

3.11 END COATING SOLUBILITY TEST

3.11.1 REQUIREMENT

There shall be no visible evidence of film destruction after the coated rods are immersed for 24 hours in a sodium chloride solution.

3.11.2 PROCEDURE

Prepare a salt water solution by mixing 6 ounces of common table salt (sodium chloride) per gallon of water. Immerse samples to be tested in solution for a period of 24 hours. Remove test samples from solution and wipe dry using lens tissue or a soft cloth.

3.11.3 ACCEPTANCE

Acceptable parts will show no visible evidence of film destruction.

3.12 END COATING HUMIDITY TEST

3.12.1 REQUIREMENT

There shall be no visible evidence of film deterioration after the coated rods are exposed for 24 hours to relative humidity of 95 to 100% at $120^\circ \pm 4^\circ$F.

3.12.2 PROCEDURE

Establish humidity conditions of 95% to 100% at $120^\circ \pm 4^\circ$F in temperature humidity chamber. Preheat samples to 120°F. Insert preheated samples in chamber and allow to remain for a period of 24 hours. Remove samples from chamber and wipe dry using lens tissue or soft cloth.

3.12.3 ACCEPTANCE

Acceptable parts will show no evidence of film deterioration.

APPENDIX 1

Engineering Sample Data

Rod No.	Fluorescent Lifetime (μ sec)	Rod Length (mm)	Rod Diameter (mm)	Surface Quality	Flatness	Parallelism (sec)	Perpendicularity (min)	Strain (fringe)
Specification	206-235	43^{+2}_{-0}	4.27 ± 0.02	20-5	0.2>	20	5	0.85
8334	222	44.9	4.27	<20-5	0.2>	17	1.0	.1
8335	223	44.9	4.27	<20-5	0.2>	12	0.5	.2
8336	223	44.9	4.27	<20-5	0.2>	12	2.0	.1
8337	210	44.9	4.27	sleeks	0.2>	<10	2.0	.1
8340	226	44.9	4.27	<20-5	0.2>	<10	1.0	.1
8341	222	44.9	4.27	<20-5	0.2>	12	1.5	.2
8342	226	44.9	4.27	<20-5	0.2>	10	1.0	.1
8343	222	44.9	4.27	some digs	0.2>	10	1.0	.1
8344	222	44.9	4.27	<20-5	0.2>	10	2.0	.1
8345	210	44.9	4.27	dig	0.2>	10	3.0	.1
8346	222	44.9	4.27	<20-5	0.2>	10	1.5	.1
8347	223	44.9	4.27	<20-5	0.2>	10	2.0	.1

APPENDIX 2

Confirmatory Sample Data

Rod No.	Fluorescent Lifetime (μ sec)	Rod Length (mm)	Rod Diameter (mm)	Surface Quality	Flatness	Parallelism (sec)	Perpendicularity (min)	Strain (fringe)
Specification	206-235	$43 {}^{+2}_{-0}$	4.27 ± 0.02	20-5	0.2>	20	5	0.85
R1749	213	44.6	4.27	<20-5	<0.2>	<10	2	0.5
R1757	213	44.5	4.27	<20-5	<0.2>	<10	3	<0.5
R1781	224	44.8	4.27	<20-5	<0.2>	<10	3	<0.5
R1782	232	44.7	4.27	<20-5	0.2>	<10	3	0
1750	213	44.1	4.27	<20-5	<0.2>	<10	2	0.25
R1759	213	44.4	4.27	<20-5	<0.2>	<10	4	0.25
R1760	224	44.3	4.27	<20-5	<0.2>	<10	2	<0.25
R1761	213	44.6	4.27	<20-5	<0.2>	<10	0.5	<0.25
R1764	213	44.6	4.27	20-5	0.2>	<10	2	0.25
R1765	224	44.8	4.27	20-5	0.2>	10	0.5	0.25
R1766	219	44.5	4.27	20-5	0.2>	10	3	0.25
R1767	219	44.6	4.27	20-5	0.2>	10	4	<0.5
R1768	213	44.6	4.27	20-5	0.2>	10	4.5	0.5
R1769	219	44.6	4.27	20-5	0.2>	10	2	<0.5
R1770	213	44.6	4.27	20-5	0.2>	10	5	.25
R1771	219	44.7	4.27	20-5	0.2	10	2.5	<0.25
R1772	224	44.6	4.27	20-5	0.2	10	2.5	0.2

APPENDIX 2 (Continued)

Confirmatory Sample Data

Rod No.	Fluorescent Lifetime (μ sec)	Rod Length (mm)	Rod Diameter (mm)	Surface Quality	Flatness	Parallelism (sec)	Perpendicularity (min)	Strain (fringe)
Specification	206-235	$43 {}^{+2}_{-0}$	4.27 ± 0.02	20-5	0.2>	20	5	0.85
R1773	213	44.6	4.27	20-5	0.2>	<10	2	<0.5
R1774	219	44.6	4.27	20-5	0.2>	<10	2	<0.25
R1775	219	44.6	4.27	20-5	0.2>	<10	0.5	<0.25
R1776	213	44.6	4.27	20-5	0.2>	10	0.5	0.5
R1777	224	44.6	4.27	20-5	0.2>	10	4	0.25
R1778	219	44.6	4.27	20-5	0.2	10	3.5	<0.25
R1159	211	45.0	4.27	20-5	0.2	10	1.5	0.25
R1162	208	45.0	4.27	20-5	0.2	10	1.5	0.25
R1166	228	45.0	4.27	20-5	0.2	10	1.5	0.5
R1167	211	44.2	4.27	20-5	0.2	10	2.5	0.25
R1168	211	44.9	4.27	20-5	0.2	10	1.0	0.25
R1169	208	45.0	4.27	20-5	0.2	10	2.0	0.25
R1171	228	45.0	4.27	20-5	0.2	10	1.5	0.5

APPENDIX 3

Pilot Production Data

Rod No.	Fluorescent Lifetime (μ sec)	Rod Length (mm)	Rod Diameter (mm)	Surface Quality*	Flatness (λ)	Parallelism (sec)	Perpendicularity (min)	Strain (fringes)
Specification	206-235	43^{+2}_{-0}	4.27 ± 0.02		0.2λ	20	5	0.85
7060	217	44.5	4.27	Sm.Chip	0.2	20	2.0	0.5
7061	217	44.5	4.27	Sleeks	0.2	12	1.5	0.5
7062	217	44.5	4.27	<20-5	0.2	15	3.0	0.25
7063	221	44.5	4.27	<20-5	0.2	15	0.5	<0.2
7064	221	44.5	4.27	Digs	0.2	20	1.0	0.2
7066	217	44.5	4.27	Sl & Digs	0.2	10	3.0	0.25
7068	221	44.5	4.27	Sleek	0.2	10	3.0	<0.2
7069	221	44.5	4.27	<20-5	0.2	15	3.0	0.25
7071	221	44.5	4.27	<20-5	0.2	10	2.0	0.2
7072	217	44.5	4.27	Scratch	0.2	10	0.75	0.1
7073	221	44.5	4.27	Scratch	0.2	12	1.5	0.25
9682	214	44.7	4.27	<20-5	0.2	10	3	0.75
9683	214	44.7	4.27	<20-5	0.2	10	1.5	0.3
9684	220	44.7	4.27	<20-5	0.2	10	1	0.1
9685	220	44.7	4.27	<20-5	0.2	10	1	0.1
9686	214	44.7	4.27	Sm.Pits	0.2	10	2.5	0.1
9687	220	44.7	4.27	<20-5	0.2	13	2.5	0.5
9688	214	44.7	4.27	<20-5	0.2	10	1	0.2
9689	220	44.7	4.27	<20-5	0.2	10	2	0.5
9700	220	44.7	4.27	Sm.Chip	0.2	10	1	0.1

*Scratch and dig per MIL-O-13830

APPENDIX 3 (Continued)

Pilot Production Data

Rod No.	Fluorescent Lifetime (μ sec)	Rod Length (mm)	Rod Diameter (mm)	Surface Quality*	Flatness (λ)	Parallelism (sec)	Perpendicularity (min)	Strain (fringes)
Specification	206-235	43^{+2}_{-0}	4.27 ± 0.02	20-5	0.2λ	20	5	0.85
10131	213	44.9	4.27	<20-5	0.2	12	1	0.2
11303	219	45.0	4.27	<20-5	0.2	10	3.0	<0.1
11305	224	45.0	4.27	<20-5	0.2	12	2.5	<0.2
11310	219	45.0	4.27	<20-5	0.2	15	2.0	<0.2
11313	219	45.0	4.27	<20-5	0.2	12	2.0	<0.1
R1150	213	43.7	4.27	<20-5	0.2	10	1.5	<0.1
R011	216	43.2	4.27	<20-5	0.2	10	5	<0.1
10113	213	43.0	4.27	<20-5	0.2	<10	2	<0.2
R1272	213	43.4	4.27	<20-5	0.2	10	0.5	<0.1
R1503	219	44.1	4.27	<20-5	0.2	<10	1.5	0.3
R1172	228	44.2	4.27	<20-5	0.2	10	1.5	0.1
R1173	217	45.0	4.27	<20-5	0.2	10	1.0	0.5
R2077	226	45.0	4.27	<20-5	0.2	10	3.0	0.2
R2263	228	45.0	4.27	<20-5	0.2	10	1.0	<0.5
R2264	224	44.9	4.27	<20-5	0.2	12	2.0	<0.1
R2265	224	44.9	4.27	<20-5	0.2	10	1.0	0.1
R2268	228	44.9	4.27	<20-5	0.2	10	2.5	<0.1
R2269	224	45.0	4.27	<20-5	0.2	15	3.5	0.1
R2270	224	45.0	4.27	<20-5	0.2	10	2.5	0.25
R2271	224	44.9	4.27	<20-5	0.2	10	1.5	0.1

* Scratch and dig per MIL-O-13830

APPENDIX 3 (Continued)

Pilot Production Data

Rod No.	Fluorescent Lifetime (μ sec)	Rod Length (mm)	Rod Diameter (mm)	Surface Quality*	Flatness (λ)	Parallelism (sec)	Perpendicularity (min)	Strain (fringes)
Specification	206-235	43^{+2}_{-0}	4.27 ± 0.02	20-5	0.2λ	20	5	0.85
9703	220	44.7	4.27	<20-5	0.2	13		0.75
9704	220	44.7	4.27	<20-5	0.2	10	1.5	0.5
9705	220	44.7	4.27	<20-5	0.2	10	2	0.2
9706	230	44.7	4.27	<20-5	0.2	20	1.5	0.1
9707	230	44.7	4.27	<20-5	0.2	10	1.0	0.2
10115	213	44.9	4.27	<20-5	0.2	12	3	0.2
10117	213	44.9	4.27	<20-5	0.2	10	2.5	<0.1
10118	213	44.9	4.27	<20-5	0.2	12	1.5	0.1
10119	213	44.9	4.27	<20-5	0.2	10	2	0.1
10120	213	44.9	4.27	<20-5	0.2	10	3	0.1
10121	213	44.9	4.27	<20-5	0.2	10	0.5	0.1
10122	213	44.9	4.27	<20-5	0.2	10	1	0.1
10123	213	44.9	4.27	<20-5	0.2	10	2.5	0.2
10124	213	44.9	4.27	<20-5	0.2	10	1.5	0.1
10125	213	44.9	4.27	<20-5	0.2	10	1.5	0.1
10126	213	44.9	4.27	<20-5	0.2	10	1.5	0.2
10127	213	44.9	4.27	<20-5	0.2	12	1.5	0.2
10128	213	44.9	4.27	<20-5	0.2	12	1.5	0.2
10129	213	44.9	4.27	<20-5	0.2	12	1.5	0.1
10130	213	44.9	4.27	<20-5	0.2	12	2.0	0.2

* Scratch and dig per MIL-O-13830

APPENDIX 3 (Continued)

Pilot Production Data

Rod No.	Fluorescent Lifetime (μ sec)	Rod Length (mm)	Rod Diameter (mm)	Surface Quality*	Flatness (λ)	Parallelism (sec)	Perpendicularity (min)	Strain (fringes)
Specification	206-235	$43 {}^{+2}_{-0}$	4.27 ± 0.02	20-5	0.2λ	20	5	0.85
R2282	216	44.9	4.27	20-5	0.2	10	1.5	0.1
R2286	216	44.7	4.27	20-5	0.2	10	5.0	0.2
R2291	220	44.8	4.27	20-5	0.2	<10	2.0	0.25
R2292	220	44.8	4.27	20-5	0.2	10	2.0	0.1
R2369	230	44.6	4.27	20-5	0.2	<10	4.0	0.5
R2374	232	44.6	4.27	20-5	0.2	<10	3.5	0.5
R2378	232	44.6	4.27	20-5	0.2	10	3.0	0.3
R2420	232	45.0	4.27	20-5	0.2	10	2.0	0.75
R2423	232	45.0	4.27	20-5	0.2	10	2.5	0.5
R2424	232	45.0	4.27	20-5	0.2	10	1.0	0.2
R2427	232	45.0	4.27	20-5	0.2	12	1.5	0.2
R2430	224	45.0	4.27	20-5	0.2	10	2.0	0.5
R2431	232	45.0	4.27	20-5	0.2	10	2.0	0.25
R2450	232	44.7	4.27	20-5	0.2	10	1.0	0.2
R2451	232	45.0	4.27	20-5	0.2	10	0.5	0.25
R2453	224	45.0	4.27	20-5	0.2	10	3.5	0.5
R2461	232	45.0	4.27	20-5	0.2	10	1.5	0.1
R2463	224	45.0	4.27	20-5	0.2	10	1.0	0.2
9701	220	44.7	4.27	Sm.Chip	0.2	10	1.5	0.3
9702	220	44.7	4.27	Sm.Chip	0.2	12	1.0	0.1

* Scratch and dig per MIL-O-13830

APPENDIX 3 (Continued)

Pilot Production Data

Rod No.	Fluorescent Lifetime (μ sec)	Rod Length (mm)	Rod Diameter (mm)	Surface Quality*	Flatness (λ)	Parallelism (sec)	Perpendicularity (min)	Strain (fringes)
Specification	206-235	43^{+2}_{-0}	4.27 ± 0.02	20-5	0.2 λ	20	5	0.85
R2851	232	43.8	4.27	20-5	0.2	<10	3	0.3
R3088	224	43.9	4.27	20-5	0.2	<10	1.5	0.1
R3155	228	43.6	4.27	20-5	0.2	<10	3.0	0.2
R3546	219	44.7	4.27	20-5	0.2	12	1.5	0.8
R3581	219	45.0	4.27	20-5	0.2	15	1.5	0.8
R3851	232	44.0	4.27	20-5	0.2	<10	4.5	0.1
R1744	224	45.0	4.27	20-5	0.2	<10	1.0	0.5
R1798	224	45.0	4.27	20-5	0.2	<10	0.5	0.7
R2051	228	45.0	4.27	20-5	0.2	<10	2.0	0.8
R2320	232	45	4.27	20-5	0.2	<10	3.0	0.5
R3040	228	45.0	4.27	20-5	0.2	<10	2.0	0.2
R3157	224	45.0	4.27	20-5	0.2	<10	2.0	0.8
R3159	232	45.0	4.27	20-5	0.2	10	1.0	0.2
R3169	219	45.0	4.27	20-5	0.2	<10	2.5	0.5
R3349	232	45.0	4.27	20-5	0.2	<10	2.5	0.5
R3419	228	45.0	4.27	20-5	0.2	<10	1.0	0.2
R3578	232	45.0	4.27	20-5	0.2	<10	1.5	0.7
R3587	224	45.0	4.27	20-5	0.2	12	2.5	0.8
R3694	224	45.0	4.27	20-5	0.2	<10	0.5	0.5
R3832	224	45.0	4.27	20-5	0.2	<10	1.0	0.2
R3834	224	45.0	4.27	20-5	0.2	<10	1.5	0.5

* Scratch and dig per MIL-O-13830

APPENDIX 4

Test Equipment

Item	Requirements
Xenon flashlamp and power supply	Flashlamp duration
1.06 μm blocking filter	Less than 0.0001% transmission at 1.06μ
Detector	S-1 surface
Oscilloscope - Tektronix Model 7704	Camera equipped Time base 100μ sec/div.
Mitotoyu Calipers Model 505-637	Least count of 0.1 mm or better
Starrett Model 483 V-Anvil Micrometer	Least count of 0.01 mm or better
Nikon Model 6 Shadowgraph	Least count of 0.01 mm or better
Nikon Model 2100 Autocollmator	Resolution of 1 min of arc
Scratch & Dig Samples R.H. Beal Model 667 and viewing fixture Model 268	Per MIL-0-13830
Nikon Model 70702 binocular microscope and illuminator	10X magnification
Optical flats	Flat to λ/10
Fizeau Interferometer 632.8 nm laser source beam expansion optics viewing screen	Capable of positioning sample and measuring optical parallelism to 0.5 fringes (4 seconds)
Twyman-Green Interferometer Perkin Elmer Model 723	Capable of measuring wavefront distortion to λ/10
Tenny Model TH27 Temperature Humidity Chamber	Capable of attaining 95-100% humidity at 120°F ± 4°F
Cary Model 14 Spectrophotometer and reflectivity attachment	Capable of measuring reflectivities from 01.% to 100% at 1.06μ

APPENDIX 5

List of Attendees
Process Demonstration
July 22, 1980

Name	Affiliation
Mr. J. Paul	Night Vision & Electro Optics Laboratory Fort Belvoir, VA
Mr. D. Viechnicki	U.S. Army Material Research Agency Watertown, MA
Mr. R. Morris	Allied Chemical Corporation Morristown, NJ
Mr. H. Heynau	Norden Division of United Technologies Corp. Norwalk, CT
Mr. P. Warren	Union Carbide Corp San Diego, CA
Mr. J. Zola	Philips Laboratory Briarcliff Manor, NY

The following members of Airtron's technical staff were in attendance:

R. Belt
D. Dentz
S. Turner
M. Moody

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1. J.E. Geusic, H.M. Marcos, and L.G. Van Uitert, Appl. Phys. Letters, 4, 182 (1964).

2. R.F. Belt, R.C. Puttbach, J.R. Latore, and D. Dentz, Contract No. DAAB-05-71-C-2611, Final Report, Dec. 1972, "Production Engineering of Nd:YAG Laser Rods for Laser Illuminator Transmitters".

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